Leveraging Resources through Collaboration

MODELING OF MW-CLASS MAGNETOPLASMADYNAMIC THRUSTERS USING THE MACH2 CODE

GLENN RESEARCH CENTER

DESIGN AND FABRICATION OF A GW-LEVEL MPD PLASMA SOURCE FOR FUSION PROPULSION APPLICATIONS

THE OHIO STATE UNIVERSITY

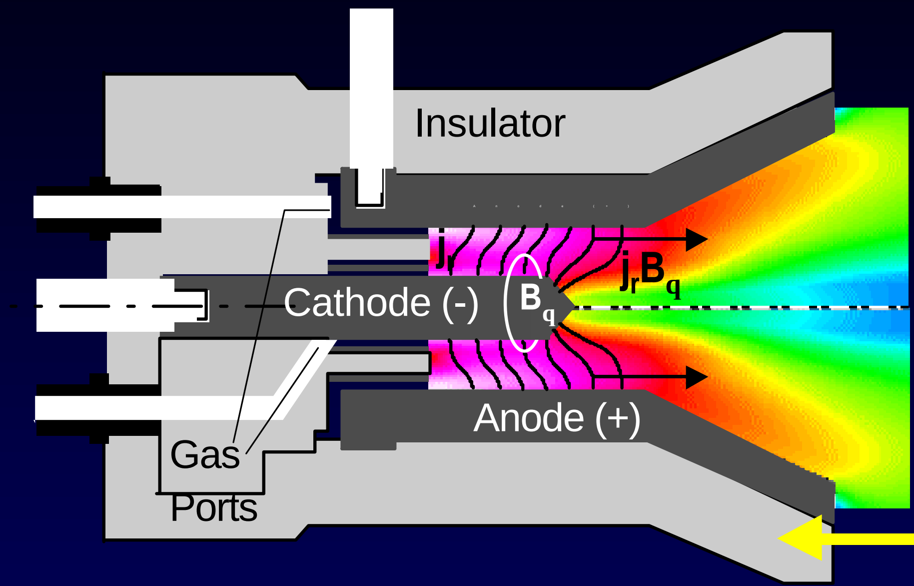
Los Alamos NATIONAL LABORATORY

An Employee-Owned Company

The Magnetohydrodynamics (MHD) Code, MACH2
Physical Model

- Time-dependent, 2-dimensional axisymmetric simulation tool for complex planar or cylindrical geometries
- Quasi-neutral, Viscous Compressible Fluid with Elastic-plastic Package, Ablation Models and Multi-Material Capability
- Multi-temperature: Electron, Ion, Radiation Various Radiation Models With Real Semi-empirical Opacities.
- Resistive-Hall-MHD with Braginskii Transport, Multi-ported Circuit Solver (e.g. LRC, AdvLRC, PFN), Various Models For Anomalous Resistivity and Electron-Neutral Contributions
- Analytic or Real Semi-empirical (SESAME) Equations of State, LTE Ionization State

The Magnetoplasmadynamic (MPD) Thruster is Conceptually Competitive. (even w/o applied fields)



Intermediate 2000s < I_{sp} < 7000s

High Thrust > 100N (MW Power)

Operationally Simple and Robust

<u>MY-II</u>: Self-field and Applied-field operation at 0.5-6 MW, Hydrogen $11 < J^2/m < 240$ (kA^2-s/g)

Challenges: Efficiency and Lifetime

Thrust Mechanisms are well understood, but insufficient to improve h.

Efficiency improves with increasing Power, but …

Onset of electrode erosion limits lifetime (… and degrades efficiency).

Energy losses: Fall Voltage, Frozen Flow, Conduction, Radiation.

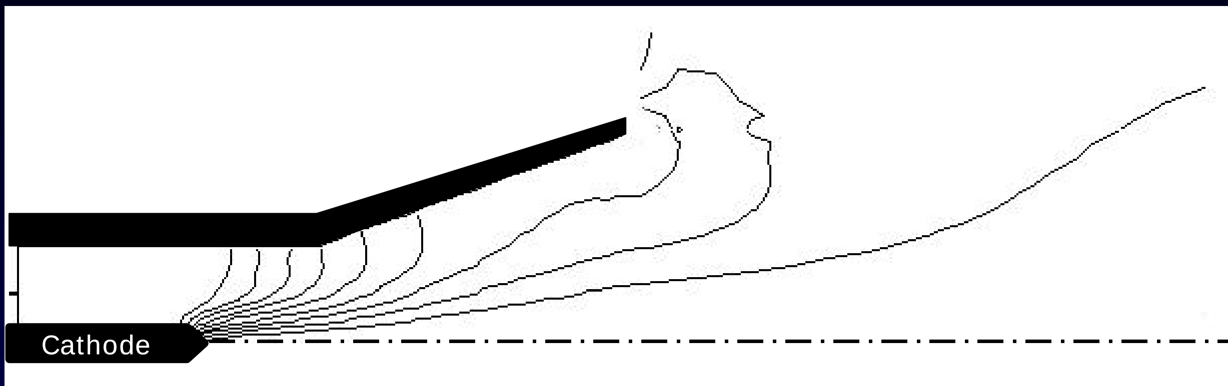
Self-field Acceleration

$$\eta = \frac{T^2}{2\dot{m}JV} < 50\%$$

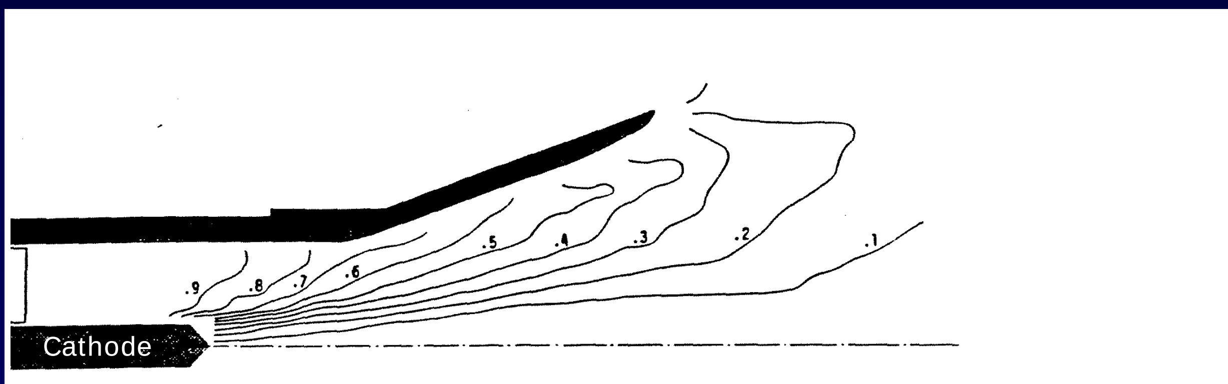
MACH2 simulations of MW-class MPD thrusters.
Physics: Real EOS for Hydrogen propellant, Two-temperature, viscous fluid.

GRC

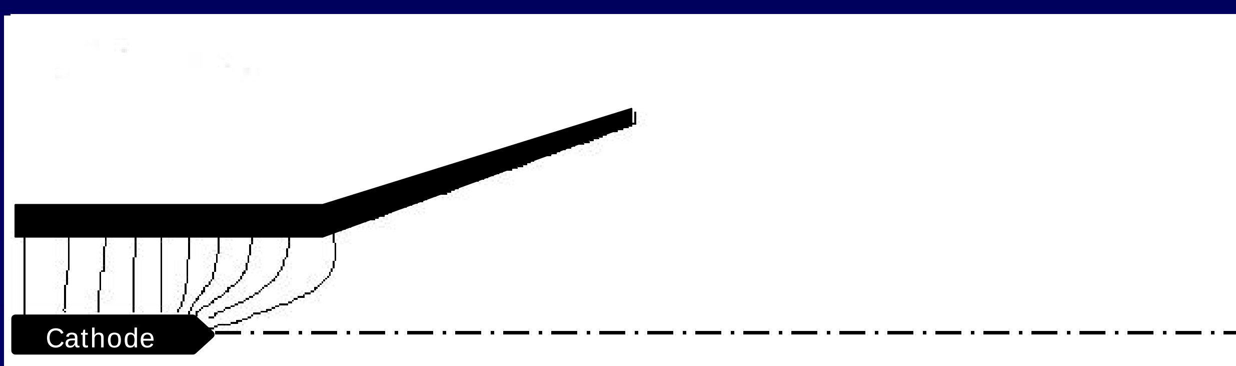
Current Distribution



MACH2
m=1.37g/s, J=10kA,
V=183V, Thrust=36.9N,
Neutral Resistivity



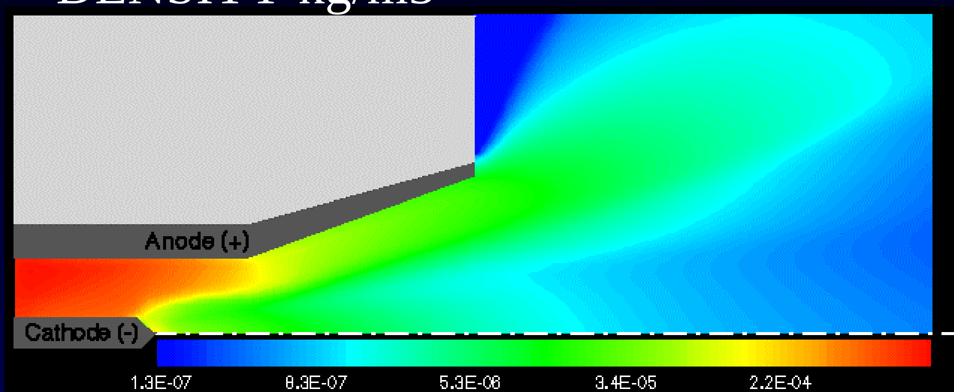
Experiment – 2MW
m=1.37g/s, J=10kA,
V=200V ,Thrust=34N
h=21%



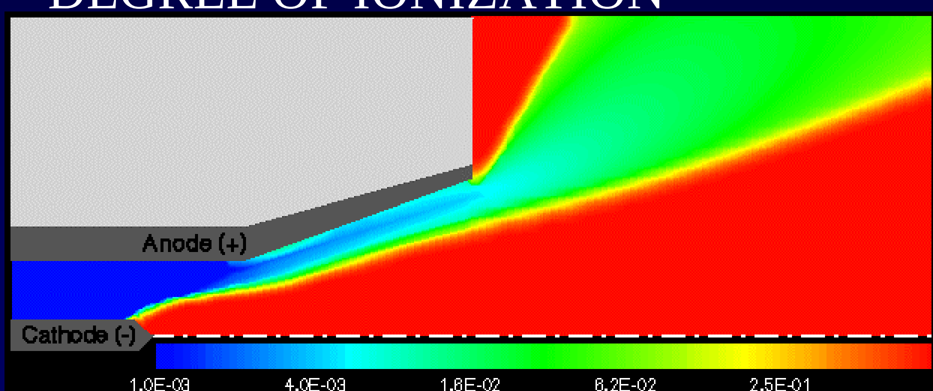
MACH2
m=1.37g/s, J=10kA,
V=108V, Thrust=32.4N,
Classical Resistivity

TO DESIGN BETTER THRUSTERS WE NEED TO QUANTIFY DEPOSITION INTO DIFFERENT ENERGY MODES.

DENSITY kg/m3



DEGREE OF IONIZATION



INTERROGATION OF THE 10 kA CASE

<u>POWER DEPOSITION</u>

THRUST_z = 0.5 MW

THRUST_r = 0.123 MW

DISS-IONZN = 0.608 MW

THRML BDY = 0.154 MW

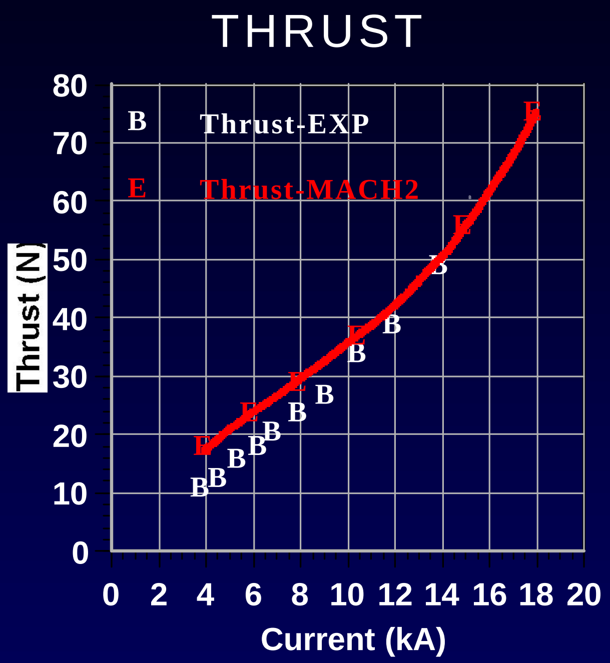
THERMAL = 0.445 MW

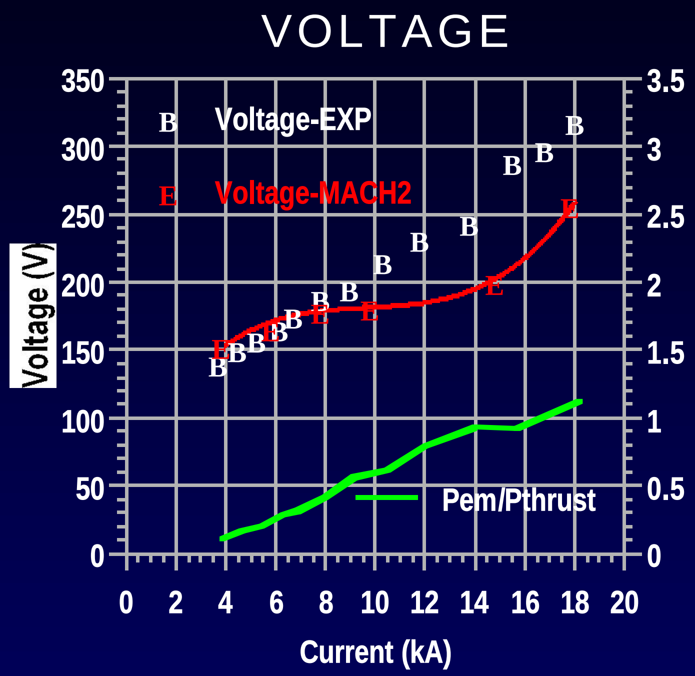
FALL VOLTAGE = 0.17 MW

THE MAIN INEFFICIENCY IS DUE TO FROZEN-FLOW LOSSES = 1.053 MW (2 MW TOTAL) <u>NOT FALL VOLTAGE LOSSES</u> !!!! IF ONLY WE COULD RECOVER 50% AND RADIAL LOSSES …

THRUST = 56N,
Isp = 4166s,
η = 57%

Further Insights Are Gained By Comparisons Over A Range Of Discharge Currents.

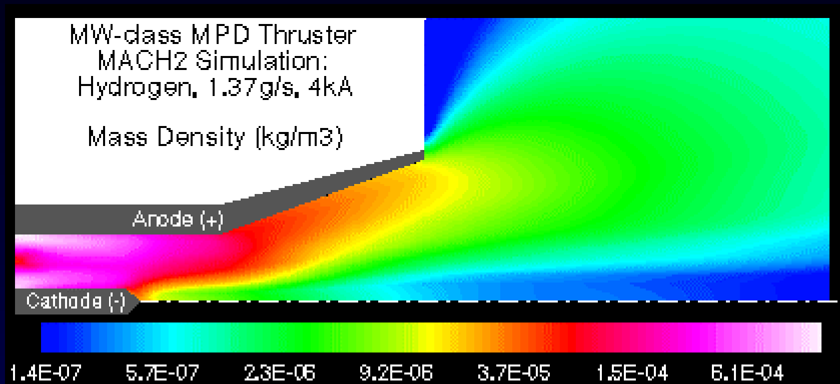




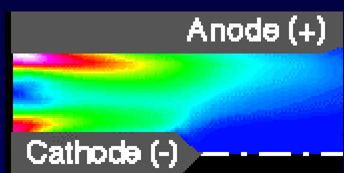
Current Distribution implies design directions that will minimize Fall Voltage losses.

	P_{FF}/P_{TOT}	P_{FV}/P_{TOT}	Efficiency
E/Thermal-4kA	0.83	~0	8%
50/50-10kA	0.6	0.09	21%
E/Magnetic-18kA	0.4	0.2	36%

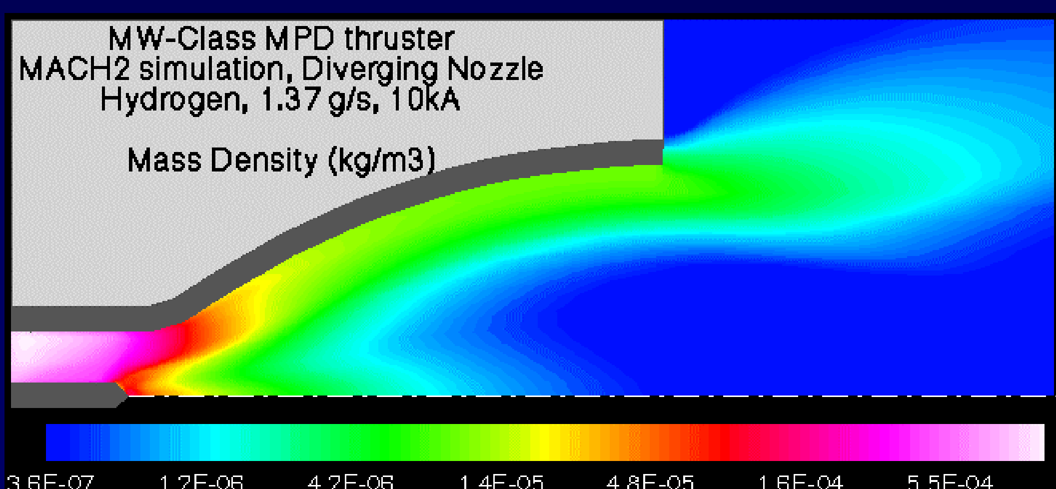
Ongoing Activities to Further Improve Understanding and Design Efficient Thrusters



Upgrade MACH2 to include mass-injection profiles that correlate better to experimental schemes.



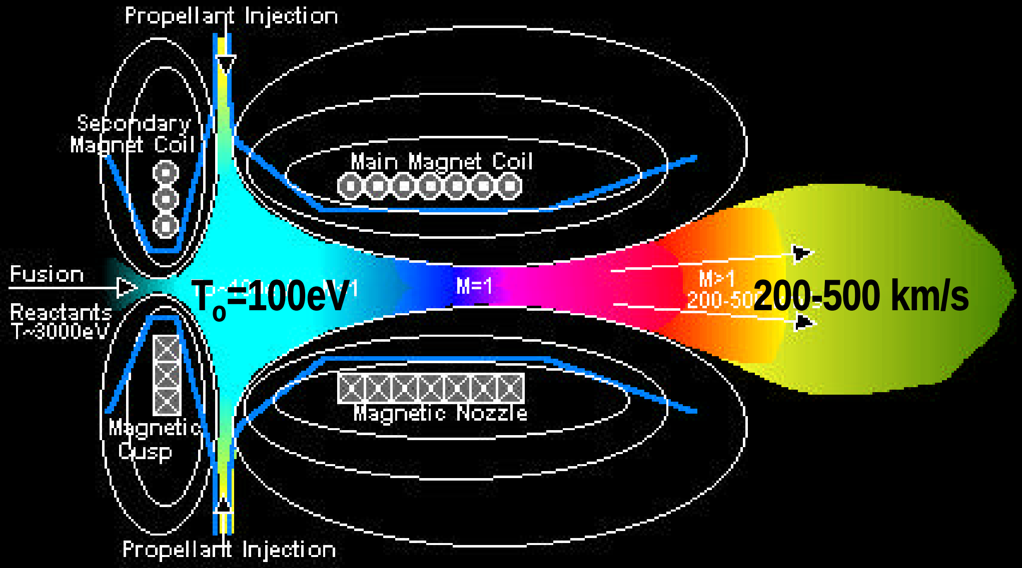
Upgrade MACH2 to include near-electrode sheath models that calculate Fall voltage and electrode erosion/ablation.



With new understanding for minimal Fall voltage losses, we are utilizing MACH2 to design nozzle configurations that will reduce frozen-flow losses.

Magnetic Nozzle Studies for Fusion Propulsion Applications

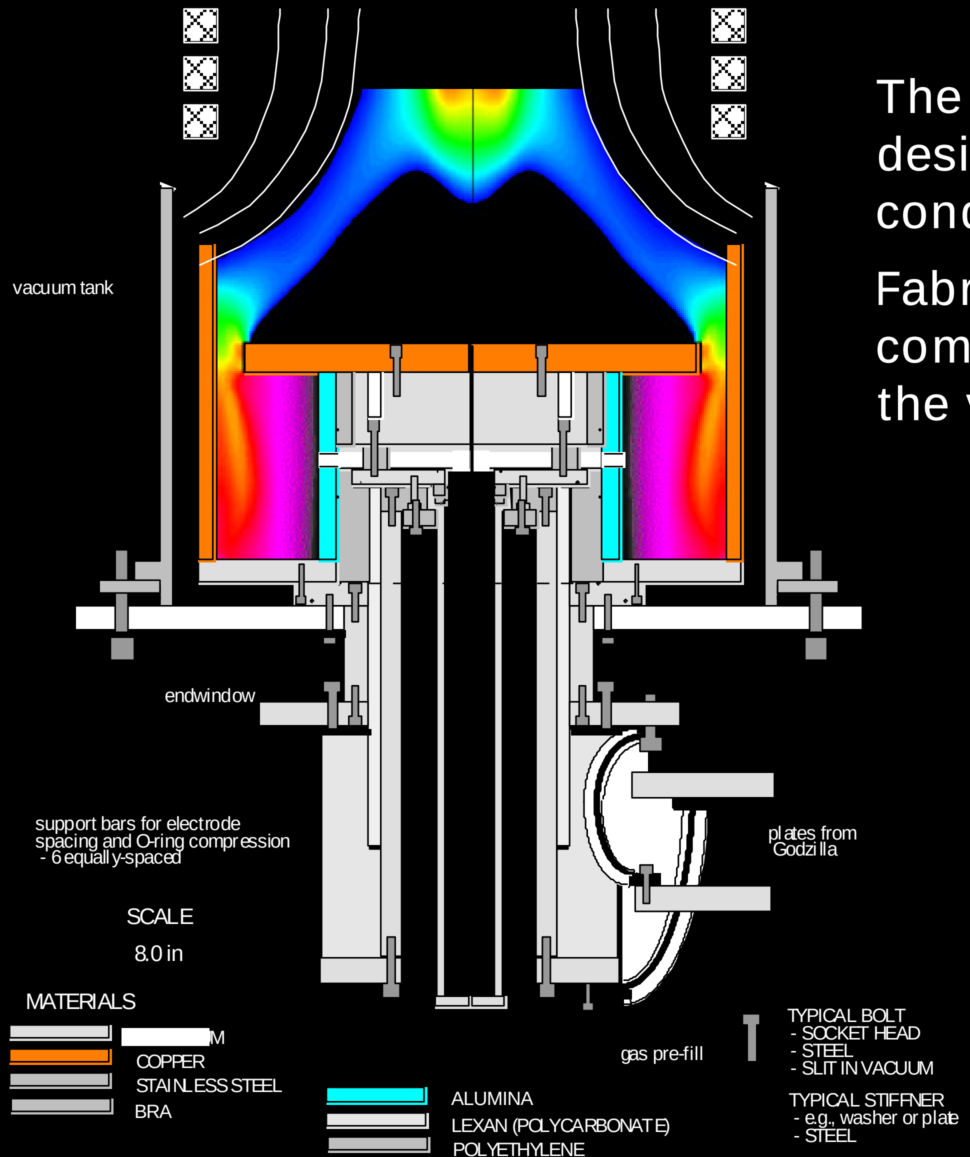
Fusion Propulsion System Concept



GW-level Capacitor Bank

Energy: 1.6 MJ
Pulse: 1.6 msec
Voltage: 6 kV
Current: 0.33 MA

The GW-level MPD source will electromagnetically deposit energy to emulate the propulsion system's stagnation conditions.



The MACH2 code has aided in designing the geometry and operating conditions.

Fabrication and assembly have been completed. Operation is anticipated in the very near future.